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Front cover: The change-over during incubation. The Grebe at the top of the photo is leaving the nest, while the one at the bottom is arriving. Photo Jurrie Hubregtse. See page 118.

Assessment of the monitoring of ground-dwelling mammals in northern Western Port, Victoria

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Abstract
Melbourne is located in a region of relatively high biodiversity and the region continues to play an important role in the conservation of local, state and national biodiversity. This study represents the first systematic, broad-scale survey of mammals over an area of 795 km² between Frankston and Bayles, including the rapidly urbanising south-east growth corridor, adjacent agricultural area, and nature conservation reserves around Western Port, including Bass Coast. Covert camera trapping was used continuously for up to 2010 days or over a period of 20–100 days. Nineteen species of mammal were recorded from 404 survey sites. These species comprised 11 native and 8 introduced taxa. At least one mammal taxon was detected at 322 (79%) of the survey sites. At any site, the largest number of species recorded was 12 and the maximum number of native species was 8. Our survey confirms that the region continues to support a rich mammal fauna, including iconic Australian native taxa. The new records refine distribution patterns and emphasise that the complex rural and peri-urban nature of this study area is particularly challenging for mammalian conservation. (*The Victorian Naturalist* **135 (4)**, 2018, 96–107)

Keywords: biodiversity, camera trap, Southern Brown Bandicoot, mammal distribution, peri-urban

Introduction

Like many urban areas, Melbourne is located in a region of relatively high biodiversity (Menkhorst 1995; Ives *et al.* 2016; Cresswell and Murphy 2016). Cities and towns are often founded where factors such as high soil fertility or moisture produce rich, productive landscapes that support a large number of plant and animal taxa, so urban and high biodiversity areas coincide (Ricketts and Imhoff 2003). Unusually, Melbourne is also situated at the junction of major biogeographic regions, and supports a diverse range of habitat types (van der Ree 2004). As a consequence, many species, including a disproportionately high number of Victoria's threatened species, have distributions that overlap Melbourne's urban growth boundary (Ives *et al.* 2016). The city's biodiversity also includes a concentration of the state's native and exotic mammal fauna (Menkhorst 1995, van der Ree 2004). Cities like Melbourne will continue to play an important role in the conservation of local, state and national biodiversity, including some of Australia's iconic wildlife species.

As Melbourne continues to expand there will be growing pressure on the faunal populations that inhabit surrounding land. Urbanisation carries with it a number of immediate anthropogenic stressors including: habitat loss; degradation and fragmentation; introduction of exotic plants and animals; changes in nutrient and water cycles; pollutants; disease and road mortality (McKinney 2008; Hardman 2011). While urban green spaces in older developed suburbs play a role in native species conservation, there is a clear need to plan and manage newer urban development to maximise biodiversity outcomes (van der Ree 2004). With the recent expansion of the urban growth boundary (Department of Environment, Land, Water and Planning (DELWP), Victoria 2017), there is also a need to inform the planning and development of new suburbs of Melbourne. These areas will become new urban 'frontiers'.

Since 2002, the Western Port Biosphere Reserve Foundation Ltd has been involved in a range of management and research projects targeting the nationally endangered Southern Brown Bandicoot *Isoodon obesulus obesulus* in the Western Port region. Southern Brown Bandicoot is a species that in many ways epitomises the struggle between wildlife and urban development (Dixon 1966; Seebeck 1977; Maclagan 2016). Although once widespread in

Melbourne's south-east, bandicoots are now largely absent from established urban areas and persist only in the peri-urban/rural interface (Seebeck 1977; Menkhorst 1995; Coates *et al.* 2008; Menkhorst and Loyn 2011; Maclagan 2016; Maclagan *et al.* 2018). In recent decades, remnant populations in the Melbourne region do not appear to have been able to survive the process of urbanisation (Coates *et al.* 2008), though they are surviving in a novel rural landscape (Maclagan *et al.* 2018). However, bandicoots are only one of a group of iconic wildlife taxa that persist in rural regions on the outskirts of cities and are likely to be affected by urban growth. Understanding these distributions is vital to effectively managing remaining native mammal populations (van der Ree 2004).

There are relatively few systematic field surveys of the mammal fauna of the greater Melbourne area (van der Ree 2004; Menkhorst and Loyn 2011). Most existing distribution information is captured in opportunistic atlas databases, such as the Victorian Biodiversity Atlas (VBA, DELWP) or the Atlas of Living Australia (ALA, CSIRO). While providing an invaluable record of historical observations (Menkhorst and Loyn 2011), these atlases produce an incomplete picture of the distribution of significant species. Systematic 'gap filling' surveys are needed to improve the quality and spread of data to effectively inform planning and management. Unfortunately, such surveys are often problematic in urban and rural areas because of the difficulty of gaining access to many suitable sites.

In recent decades, the development of digital 'trail' camera traps has greatly improved opportunities to monitor wildlife in a range of locations (Meek *et al.* 2012). Cameras economically capture and store large amounts of data over extended periods. These devices are remotely activated, passive and non-invasive, potentially providing more 'natural' distribution records. Furthermore, cameras have the capability to sample a range of species simultaneously. In an attempt to better understand the distribution of mammals in Melbourne's south-east we deployed trail cameras across a large peri-urban/rural landscape from Frankston to Koo Wee Rup.

Methods

Study Area

The main study area extends across the region north of Western Port, Victoria, from Langwarrin in the west (38.225°S, 145.381°E) to Cora Lynn in the east (38.133°S, 145.674°E) (Figs. 1A, 1B). Additional 'Focus' surveys were conducted and are included here as part of a broader survey.

Although the area includes Pakenham and Cranbourne growth corridors, the majority of the study area remains rural in character with larger holdings of agricultural land and relatively low housing density. The area is dominated by the former Koo Wee Rup ('Great') Swamp; an area that was drained and cleared during the late 1800s (Yugovic and Mitchell 2006; Davidson 2014). Native vegetation in this region is now largely confined to coastal fringe, roadsides and flood mitigation (drainage) channels (Yugovic and Mitchell 2006; Coates *et al.* 2008). There are several modest bushland reserves (up to 711 ha) including North Western Port Nature Conservation Reserve (including Quail Island, Woodlot Lane); the Royal Botanic Gardens Victoria, Cranbourne Gardens (hereafter Cranbourne Gardens); Bayles Fauna Reserve (38.178°S, 145.567°E) and three Nature Conservation Reserves (NCRs)—Adams Creek, The Gurdies and Grantville—in the Bass Coast region.

Sample sites, equipment, data sets and data management

Four categories of sample site were used in the survey:

1. 'Fixed' sites were representative locations surveyed for extended periods between 1 January 2011 and 31 December 2016. From July 2013, 5 additional cameras were established in 2 regions adjacent to Cranbourne Gardens and West Gippsland NCR, and a further 11 cameras near Melbourne Water flood mitigation channels. Deployment ranged from 68 to 765 days.
2. 'Short-term' sites were at the nearest suitable trap site to randomly generated locations. The site was chosen where there was good cover of shrubs and ground layer plants, access (avoiding private land where we did not have approval) and security (from human

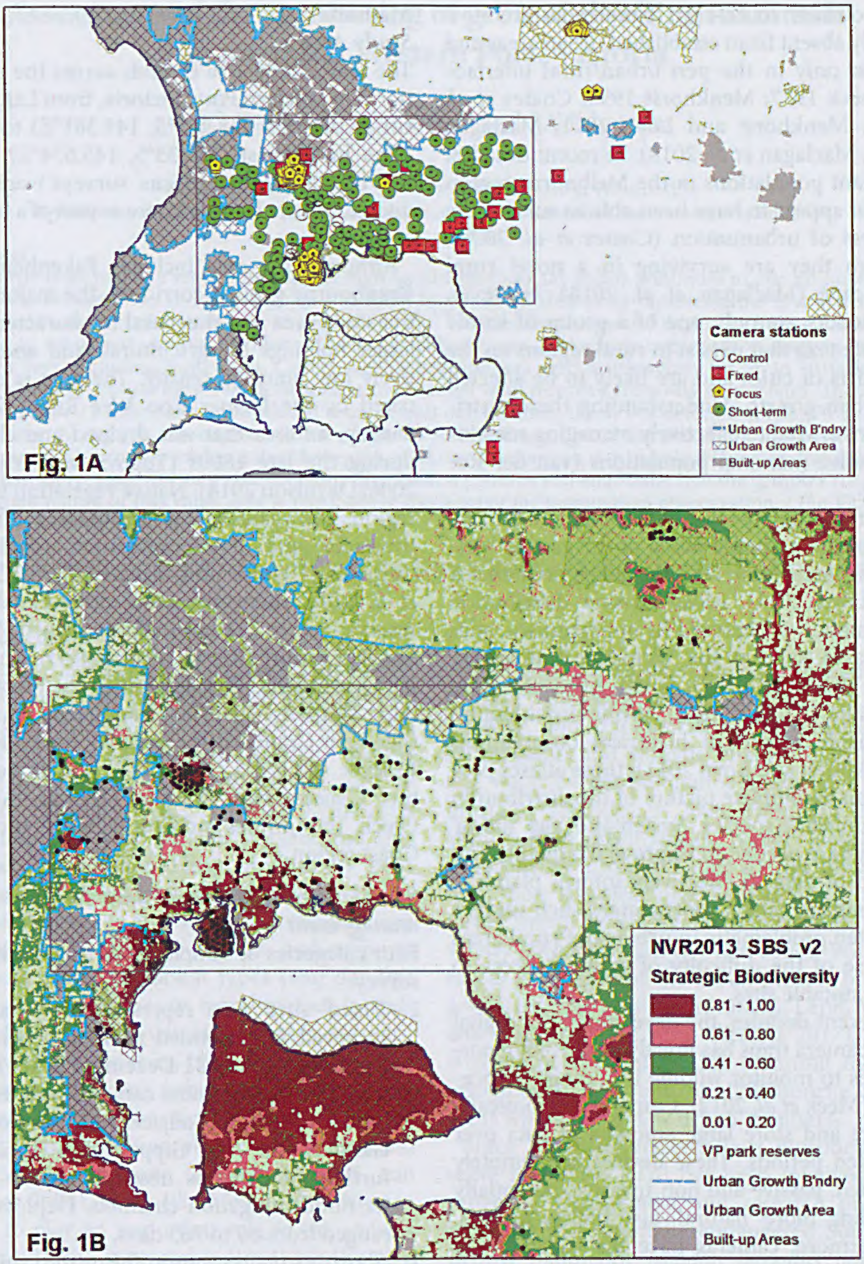


Fig. 1. Map of the study area (rectangle) and the surrounds, south-east of Melbourne. The four kinds of survey (Short-term, Fixed, Focus and Control; see Methods) are mapped with built-up areas, the urban growth area and native intact bushland (Fig. 1A). The biodiversity value of the landscape as measured by Strategic Biodiversity Score from DELWP NaturePrint2 shows the high value Cranbourne Gardens and North Western Port Nature Conservation Reserve contrasting with the very low values rural area in most of the study area (see text). The camera trap sites are mapped (Fig. 1A).

interference). They were surveyed for nominally 30 days (20–100 d, except for five sites, initially overlooked).

3. 'Focus' sites were localities of special interest: Quail Island (30 sites surveyed from 11 July 2014 to 1 October 2014, 47–74 d, and 31 sites surveyed from 5 December 2014 to 7 April 2015, 64–88 d); Mt Cannibal Flora and Fauna Reserve, Garfield North (6 sites between 1 July and 18 August 2014, 48 d, and between 6 May and 19 June 2015, 44 d); and Black Snake Gully, an enclave of private properties within the Bunyip State Park (12 sites from 31 July to 22 September 2015, 53 d). A regular grid was used to position these 'Focus' deployments. Additional data sets from partners were included from S Maclagan, Deakin University and Cranbourne Gardens.
4. 'Control' sites in the Tooradin region were established prior to and coincident with a fox control program conducted between December 2015 and March 2016.

Sites were selected to represent the vegetation and land use of the local landscape. Camera trap sites for the categories are shown in Fig. 1A. The quality of habitats and trap sites are shown in Fig. 1B. The Strategic Biodiversity Score of NaturePrint2 was used as a proxy for habitat quality. NaturePrint2 is part of the DELWP Nature Kit, a product and tool for managing nature conservation in Victoria (https://www.environment.vic.gov.au/biodiversity/natureprint). The score incorporates species distributions, biodiversity values, habitat connectivity and recoverability measures. The Geospatial Information System (GIS) data for the Planning Scheme Urban Growth Boundary–Vicmap Planning were published on 9 February 2017 (Spatial Datamart Victoria 2017a) and the built-up areas were current at 15 July 2016 (Spatial Datamart Victoria 2017b).

Surveys were conducted using Reconyx HC600 passive infrared cameras set at maximum sensitivity, recording sets of three high resolution images at one second intervals with no delay between triggers. These cameras use a covert 'no-glow' infra-red flash at night that is effectively invisible to the mammal species likely to be encountered in the study area (Meek *et al.* 2014). The cameras were positioned between 0.25–1 m above the ground, generally facing south and slightly downwards, to photograph the ground in front of the camera up to 1.5 m away.

Bait attractants were not used at the majority of trap stations. However, at a small subset—the Maclagan Deakin University sites at Quail Island and Cranbourne Gardens and 28 sites within Cranbourne Gardens—a standard small mammal bait attractant in an anchored bait holder was used (T Coates 2018, pers. comm.).

The work was done under a DELWP scientific permit (No. 10007566) and permission was obtained from each land manager or land owner. An Occupational Health and Safety protocol was implemented to protect observers, especially when working on roadsides.

Images were initially 'tagged' using ExifPro software (http://www.exifpro.com). The mammal species and a unique camera site identifier were added to the Exchangeable Image File (EXIF) metadata. The majority of mammals could be identified to species level but some rodents were identified only to genus. These metadata with the image date and time were exported to an Excel spreadsheet and filtered to eliminate multiple (repeat) records on any single calendar day, to produce a record of daily presence (1) or absence (0) for each species at each site. This data set was initially processed using MS Excel, MS Access or JMP 12.1 (SAS Institute Inc.). The resulting data were imported to R software (R Core Team 2015) to ensure consistency for analysis. These records were transformed to a detection rate (detection-days per 100 camera-days) for each species at each site. The marked images were copied to a new directory and archived.

The geographical location of the sites was collected at the start and/or completion of each deployment with handheld GPS receivers (Garmin Ltd models eTrex and Geko, and Bad Elf models Surveyor and Pro+). These data were processed with Garfield Pro and DNR GPS software and added to a GIS project in ESRI Arc GIS 10.4 and 10.6 and X-Tools Extension. The random and regular survey points were generated with X-tools v12 (https://xtools.pro/en/overview/).

Results

A summary of deployment of all cameras in the study area is presented in Table 1.

Nineteen species of mammal were recorded (Table 2). These species comprised 11 native and 8 introduced taxa. At least one mammal taxon was detected at 322 (79%) survey sites. The largest number of mammal species recorded at any site was 12 and the maximum number of native species recorded at any site was 8 (Table 3).

The taxa most likely to be detected were Red Fox *Vulpes vulpes* (3354 of detections, 48% of sites), Black Wallaby *Wallabia bicolor* (4025 of detections, 43% of sites) and European Rabbit *Oryctolagus cuniculus* (4204 detections, 36% of sites). The taxa least likely to be detected were Agile Antechinus *Antechinus agilis* (3 detections, 0.25% of sites), Sugar Glider *Petaurus breviceps* (5 detections, 0.7% of sites) and Brown Hare *Lepus capensis* (64 detections, 1.25% of sites).

Table 1. Summary of deployments giving number of cameras, the total number of days deployed and the number of calendar days the subclass was detected.

Deployment type	Camera site deployments	Deployment duration in days	Subclass	Number of daily occupancy records
Focus	165	11330	Monotreme	180
			Marsupial	3114
			Placental Mammal	855
Fixed	36	18958	Monotreme	187
			Marsupial	3720
			Placental Mammal	5581
Short-term	187	10180	Monotreme	42
			Marsupial	492
			Placental Mammal	2766
Control	15	411	NA	NA
Totals	**403**	**40879**		**16937**

Table 2. The number of survey sites where mammal species were detected (from a total of 322 sites).

Common name	Scientific name	Number of positive sites
Short-beaked Echidna	*Tachyglossus aculeatus*	89
Agile Antechinus	*Antechinus agilis*	1
Southern Brown Bandicoot	*Isoodon obesulus*	80
Common Brushtail Possum	*Trichosurus vulpecula*	98
Common Ringtail Possum	*Pseudocheirus peregrinus*	41
Sugar Glider	*Petaurus breviceps*	3
Black Wallaby	*Wallabia bicolor*	176
Eastern Grey Kangaroo	*Macropus giganteus*	17
Koala	*Phascolarctos cinereus*	30
Common Wombat	*Vombatus ursinus*	50
Swamp Rat	*Rattus lutreolus*	8
European Rabbit	*Oryctolagus cuniculus*	146
Cat (domestic and feral)	*Felis catus*	46
Red Fox	*Vulpes vulpes*	196
Brown Hare	*Lepus capensis*	5
Deer	*Cervus spp.*	21
Pig	*Sus scrofa*	26
Black Rat	*Rattus rattus*	92
House Mouse	*Mus musculus*	25

Table 3. The number of sites with zero to eight species of mammal, for native species and introduced species.

	Species at site								
	0	1	2	3	4	5	6	7	8
Native species	84	67	64	56	32	15	2	1	7
Introduced species	55	92	91	59	20	4	1		

Individual species distributions in the study area

Southern Brown Bandicoot Isoodon obesulus obesulus

The records show that the incidence of bandicoots was scattered widely across the eastern section of study area, particularly at sites within the former Koo Wee Rup Swamp (Fig. 2). In this area, the species was recorded at sites in the predominantly cleared agricultural landscape that extends from Cardinia to Cora Lynn. There are no large patches of native vegetation remaining in this part of the study area and Bandicoots were typically associated with narrow linear roadsides and flood-mitigation channels. By contrast, in the western half of the study area records were concentrated at sites in and around larger patches of remnant vegetation at the Cranbourne Gardens and Quail Island. The species was not detected in agricultural landscapes west of Cardinia/Tooradin.

Short-beaked Echidna Tachyglossus aculeatus

Echidnas were largely restricted to larger areas of native vegetation in nature conservation reserves such as Cranbourne Gardens, the North Western Port NCR and Woodlot Lane (Fig. 2). They were recorded infrequently at sites in predominantly agricultural landscapes.

Black Wallaby Wallabia bicolor

Black Wallabies were recorded widely across the region but most records were made in larger areas of bushland in the western and southern parts of the study area (Fig. 2). The species was recorded infrequently throughout the Koo Wee Rup Swamp area.

Common Wombat Vombatus ursinus

Common Wombats were recorded rarely anywhere outside Cranbourne Gardens (Fig. 2). There were only two other sites where the species was recorded: Woodlot Lane and Koo Wee Rup Main Drain, north of Bayles.

Koala Phascolarctos cinereus

Koala records were confined largely to North Western Port NCR (including the Yaringa area and Quail Island, Fig. 2). The species was recorded at two sites in Cranbourne Gardens and two small, isolated patches of vegetation between Cranbourne and the coast.

Common Ringtail Possum Pseudocheirus peregrinus *and Common Brushtail Possum* Trichosurus vulpecula

Common Ringtail Possum and Common Brushtail Possum were recorded across the entire region, but were more likely to be recorded at sites in the western part of the study area (Fig. 2). Brushtail Possums appeared to be more likely to be detected away from large vegetation patches than were Ringtail Possums.

Sugar Glider Petaurus breviceps

Sugar Gliders were recorded at three sites on Quail Island, and at one site at Cranbourne Gardens and Woodlot Lane.

Introduced mammals

In contrast to many of the native species, exotic mammals were recorded frequently at sites in predominantly agricultural landscapes, away from larger vegetated patches (Fig. 2). A number of the more commonly encountered introduced species (Red Fox, European Rabbit and Black Rat) were widespread throughout the study area at both coastal and inland sites, from the east to west and in and out of areas of native vegetation. Interestingly, Cats *Felis catus* were distributed widely but were absent mostly from bigger vegetated patches including the larger conservation areas such as North Western Port NCR and Cranbourne Gardens. They were detected at a quarter of Red Fox detection levels. Pigs *Sus scrofa* were confined largely to Quail Island, occurring at the majority of sites on the island. They were also recorded at The Gurdies NCR.

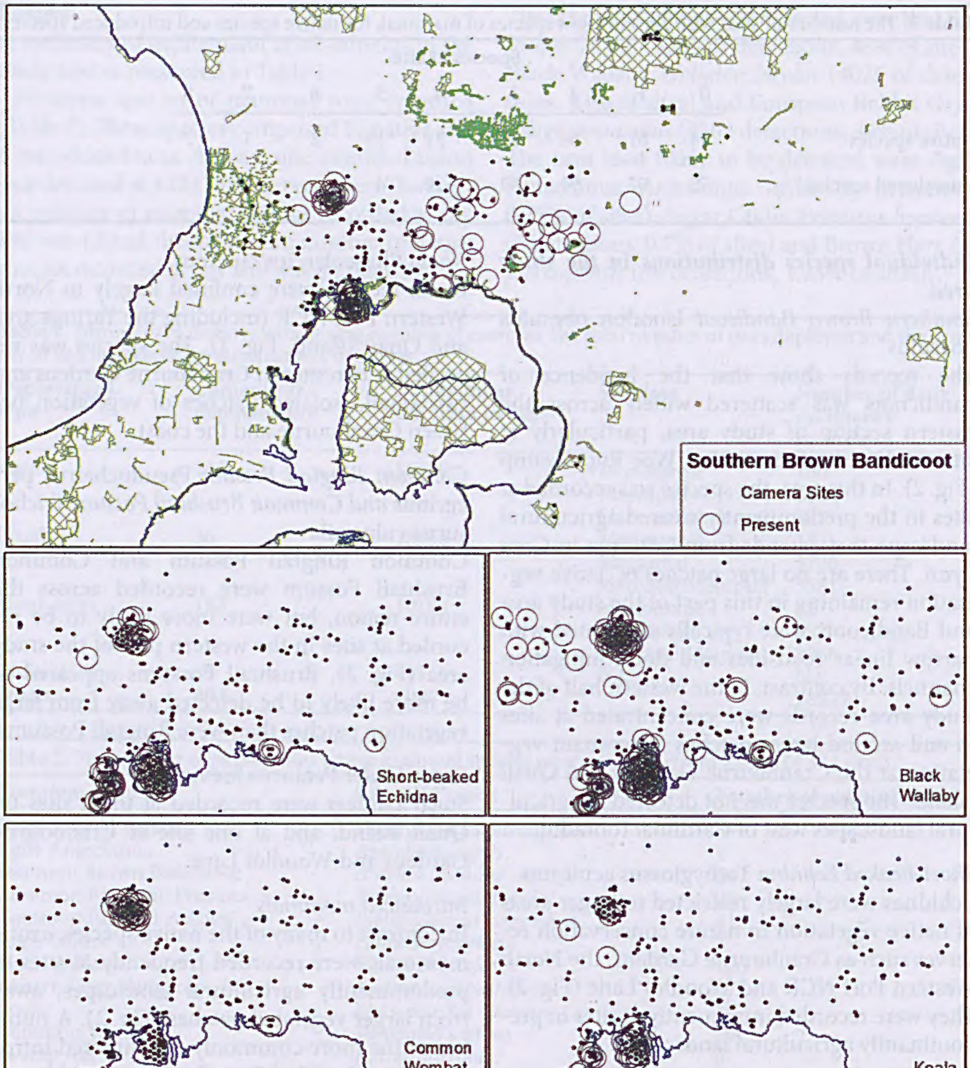
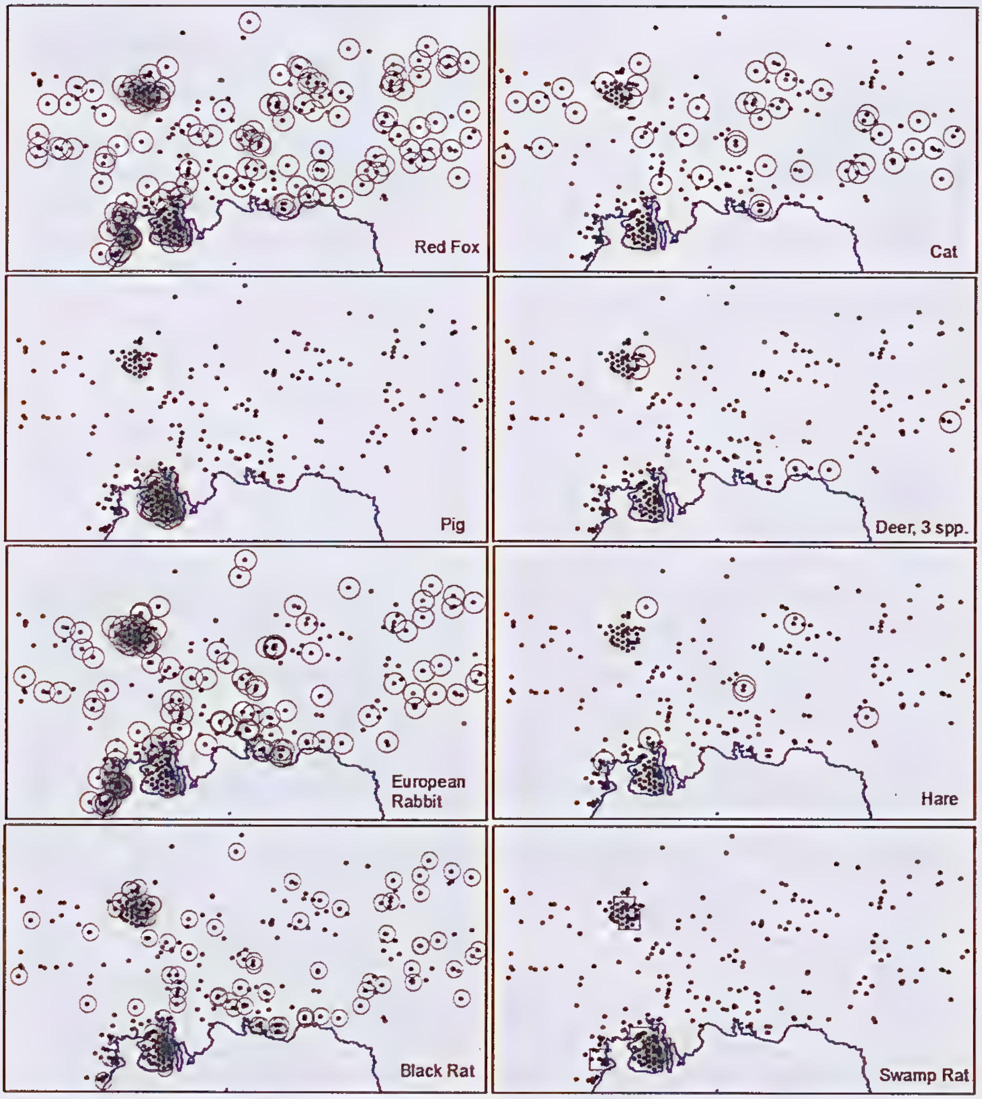


Fig. 2. Species present in main study area. Each camera trap site is marked by a small dot. An open circle marks the sites where the species was present. The species distributions for the sites beyond this subset are described below and in Table 4.

Fig. 2 cont.



Hog Deer *Cervus porcinus* were recorded once at two sites outside the Cranbourne Gardens predator fence. Sambar Deer *Cervus unicolor* were recorded at Bayles, 'The Inlets' on the Western Port coast between Tooradin and Koo Wee Rup, Mount Cannibal FFR and especially Black Snake Gully. Fallow Deer *Cervus dama* were common in the lowland forests at the Mount Cannibal FFR and Bayles Fauna Reserve.

Discussion

Mammalian diversity across the landscape

Thirty terrestrial or arboreal mammals have previously been recorded in the study area (ALA, VBA). The current survey proved effective in detecting the majority of known species and added records for two species not previously recorded from the region (Hog Deer and feral Pig). Species that were not detected during the current study were either unlikely to still

Table 4. Presence (1) and absence (0) of species at remote sites i.e. those not mapped in Fig. 2.

Species	Mt Cannibal	Black Snake Gully	Bass Coast Nature Conservation Reserves, West Gippsland
Short-beaked Echidna	1	1	1
Agile Antechinus			1
Southern Brown Bandicoot	0	0	1
Common Brushtail Possum	0	1	1
Common Ringtail Possum	0	1	1
Sugar Glider	0	0	0
Eastern Grey Kangaroo	1	1	1
Black Wallaby	1	1	1
Koala	0	1	1
Common Wombat	1	1	1
European Rabbit	1	1	1
Cat	0	0	0
Red Fox	1	1	1
Deer (all spp.)	1	1	1
No. of native species	4	7	9
No. of camera sites	12	6	5
Deployments per site	2	1	1
Duration (months) of deployment	1.5	1.5	30

occur in the region or unlikely to be detected on the ground by our camera setup. These species are Long-nosed Bandicoot *Perameles nasutu*, Ferret *Mustela putorius furo*, Bush Rat *Rattus fuscipes*, Leadbeater's Possum *Gymnobelideus leadbeateri*, Feathertail Glider *Aerobates pygmaeus*, Eastern Pygmy-possum *Cercartetus nanus*, Yellow-bellied Glider *Petaurus australis* and Greater Glider *Petauroides volans*. At least one species, New Holland Mouse *Pseudomys novaehollandiae*, has not been recorded anywhere in the region for more than 30 years and is thought to be locally extinct.

An earlier review of the fauna of the region mapped the coarse distribution of 51 terrestrial mammal species (Andrew *et al.* 1984). Like the current ALA and VBA, that work exploited a range of different data sources including historical records, literature, road-kills, opportunistic sightings and targeted surveys, to compile distribution maps. Although records are checked and validated, it is inevitable that there are errors and biases in these types of data (van der Ree 2004). For example, the sampling effort (i.e. time and resources invested) and the techniques used are not consistent across the area and tend to be biased towards sites with relatively high levels of human interest or activity, and against cryptic taxa. The present study provides an opportunity to map species distribution with a single, low-cost technique, but direct comparison with this report from 1984 is unreliable, given the different methods and spatial resolution.

Our data suggest that mammal communities differed sharply between patches of remnant vegetation and the surrounding rural matrix. Sites in bushland reserves were species-rich, supporting a high proportion of native taxa. Although native species were recorded in agricultural landscapes, these areas were typically dominated by exotic pests such as European Rabbits, Red Foxes, Cats and Black Rats. Our records suggest that these exotic species are generally much more widespread in the region than is apparent from available atlas data.

Although still clearly more likely to be detected in large patches of native vegetation, Southern Brown Bandicoot, Black Wallaby and Common Brushtail Possum were the only native species that were frequently recorded in more than 10 sites in highly modified agricultural landscapes. Bandicoots are known to be relatively common at larger sites where there is suitable vegetation cover and low predator density (Menkhorst 1995; Southwell *et al.* 2008; Coates *et al.* 2008). The species also extends into farmland within the former Koo Wee Rup

Swamp, particularly where suitable refuge areas are available (Coates *et al.* 2008; Maclagan 2016; Maclagan *et al.* 2018).

Common Brushtail Possum, one of Victoria's most widespread mammals, is able to exploit a wide range of modified, open forest habitats including roadsides, suburban parks and gardens. It is widespread and common throughout the Melbourne Metropolitan region (Menkhorst and Loyn 2011). A predominantly arboreal species, it is often seen feeding or moving across the ground and frequently triggers cameras set for terrestrial species. (Common Ringtail Possums and Sugar Gliders were also detected on the ground by cameras.) Although the Common Brushtail Possum was widespread in the study area, it appeared less likely to be recorded across Koo Wee Rup Swamp than in urban areas or remnant forest. This pattern possibly reflects the availability of suitable den sites (Menkhorst 1995).

Consistent with atlas records, our data indicate that Black Wallabies are rarely detected outside of relatively large patches of remnant vegetation in the study area. The species has not been recorded previously from the extensive Koo Wee Rup Swamp agricultural area (ALA; VBA). It appears to have always been associated more with areas of remnant forest in the foothills and coastal fringe or in smaller isolated patches of scrub and forest (ALA). In the present study, wallaby records show a concentration in larger forest or woodland patches such as Cranbourne Gardens and North Western Port NCR, where it was recorded at the majority of these sites. Some evidence suggests that the species was historically uncommon in the region (Wheelwright 1862) and that some populations may have been increasing and spreading in recent decades (Menkhorst 1995; Coates 2008).

Although Common Wombats, Echidnas and Koalas are known to occur in modified agricultural landscapes elsewhere (Strahan 1983). In this study individuals from these taxa were recorded rarely outside larger patches of remnant native vegetation. The only site where Common Wombats were known to be common in the study area was Cranbourne Gardens. An unknown number of wombats were introduced to the Gardens by wildlife carers prior to 1997 (Cranbourne Gardens 2018, unpubl.) and the species is now common at the site (Coates 2013). Consistent with atlas data, there were few records elsewhere in the study area. Echidnas, although widespread in all Victorian regions, do not appear to commonly utilise areas of extensively cleared farmland (Menkhorst 1995). Instead they rely on areas with trees and fallen logs that provide suitable sites for ant and termite colonies.

The Western Port region is an important area for Koala conservation and management. Individuals from overpopulated sites in Western Port have been used to found new colonies throughout the forested areas of southern Australia (Menkhorst 2008). Large numbers of individuals were moved around the islands and coastal regions of Western Port during last century (Warneke 1978; Lee *et al.* 1988; Martin and Handasyde 1999; Menkhorst 2008). More than 1300 Koalas were moved from Quail Island to the mainland in the mid-1940s, after 165 had been introduced to Quail Island from nearby French Island during the 1930s (Martin and Handasyde 1999). At the time, there was public concern that both Koalas and the vegetation on Quail Island were in poor condition as a result of over-browsing (Martin and Handasyde 1999; Menkhorst 2008). Several individuals from Quail Island were relocated to Cranbourne Gardens during the 1940s (VBA). Interestingly, despite the potential for rapid population growth under suitable conditions, Koalas do not now appear to be common at either Quail Island or Cranbourne Gardens.

Antechinus were not detected in the main study area, north of Western Port. Although a single individual was trapped at Cranbourne Gardens in the mid-1970s (Braithwaite 1978), there are few historical records from this region recorded in the Atlas of Living Australia or the Victorian Biodiversity Atlas. *Antechinus agilis* (as *A. stuartii*) was known from coastal areas east and west of Western Port (Andrew *et al.* 1984, Menkhorst 1995, ALA, VBA). Records also include live captures of individuals around Yaringa area (North Western Port NCR) within the last 20 years (Darren Quin, Ecology Australia 1999, unpubl.; Field Naturalists Club of Victoria—Fauna Survey Group 2001, unpubl.; Malcolm Legg 2018, pers. comm.). Despite successful recording of *Antechinus* species at

other sites, it is possible that *A. agilis* persists in the region but simply was not detected by our camera set-up. Smaller-bodied taxa are almost certainly less likely to trigger passive infrared cameras even when they are set to the highest sensitivity (Rowcliffe *et al.* 2011). However, we did record *A. agilis* at one remote site (West Gippsland, Table 2) as well as many small species, including rats, house mice and birds at many sites. Further work will be required to assess the status of *A. agilis* in the region.

The mammalian fauna of Greater Melbourne is rich; it has 65% of Victoria's species (Menkhorst and Loyn 2011). This study successfully used a new technology targeting ground-dwelling mammals, but it surveyed only a fraction of Greater Melbourne. Accurate interpretation of change requires substantial monitoring and systematic surveys. We need greater effort both over all the region and for the complete fauna if we are to manage this heritage.

Conclusion

This study represents the first systematic, broad-scale survey of mammals over an area of 795 km^2 between Frankston and Bayles, including the rapidly urbanising south-east growth corridor and the adjacent Koo Wee Rup Swamp agricultural area. Our survey confirms that the region continues to support a rich mammal fauna, including a suite of iconic Australian native taxa. The new records refine distribution patterns and emphasise that the complex rural and peri-urban nature of this study area is particularly challenging for mammalian conservation.

Generally, cleared agricultural landscapes south-east of Melbourne supported mammal communities dominated by exotic species. Foxes, rabbits, cats and rats were widespread across the region, whereas the majority of native taxa were effectively confined to larger patches of remnant native vegetation. Although small in area and few in number, patches of remnant vegetation appear to be crucial in maintaining native mammal communities in this region.

While the mammal fauna present in the 1980s is largely intact today, intensive housing developments are fragmenting the rural area. So much so, that it is likely there will be local losses of populations and species.

The variability across apparently similar trapping sites is an indication of the survey effort needed to measure change. Foxes and cats were widely distributed and their role as predators remains an important interest. These aspects are continuing to be investigated.

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The Southern Brown Bandicoot Technical Reference Group provided advice on the experimental design. Private land owners and public land managers allowed access to their properties. Vicmap provided data and the Cooperative Research Centre Spatial Information Melbourne helped with the geographical information system. Deakin University (Sarah Maclagan) and Royal Botanic Gardens Victoria shared their data. Zac Powell confirmed the identification of deer species. Ian Mansergh and three referees improved the manuscript.

Approval for the camera trapping was given by DELWP. Land managers in Parks Victoria, Melbourne Water, Frankston City Council, City of Casey and Cardinia Shire Council and private landholders approved the siting of cameras on their land and roadsides.

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Imported geological material in natural areas: impacts and management

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Abstract
Imported geological material is a critical issue in maintaining natural areas. Foreign anthropogenic geomaterial is not consistent with site geology, geomorphology, soils and hydrology. We review case studies, discuss alternatives and propose management guidelines. (*The Victorian Naturalist* **135 (4)**, 2018, 108–118)

Keywords: geodiversity, geomaterial, geoconservation, nature conservation

Introduction

Geodiversity and biodiversity are central to the understanding, appreciation, protection and management of natural areas. Geodiversity underpins biodiversity. Natural areas have land surfaces, stream beds, lake beds or seabeds largely unmodified geomorphically by human activity. Their age, diversity, scientific interest, aesthetics and other important values drive nature conservation.

Analogous to invasive species in bioconservation, geological material introduced into an area, deliberately or accidentally, is a critical issue in geoconservation. Anthropogenic geomaterial is any geological material, natural or synthetic, that occurs where it does due to human activity, having been placed there or having moved from where it was placed. It is mostly in the form of exotic geomaterial, that is, geomaterial which is not of the same geology as the receiving site. We refer to this as *alien* or *exogenous* geomaterial. Most is of industrial age (19th to 21st Century) origin and large quantities may be involved. By comparison, Aboriginal stone tools and waste flakes involve small amounts of material and have cultural value *in situ*.

Alien anthropogenic geomaterial is not consistent with site geology, geomorphology, soils and hydrology and creates a management issue in natural areas. It does not reproduce but it may spread, and can disaggregate and/or consolidate to form a surface that is biologically inhospitable.

Here we review case studies, discuss alternatives and propose management guidelines on the use of imported geomaterial in the conservation management of natural areas.

Conservation geology

The geosphere is innermost of the concentric interwoven spheres of the Earth system (Fig. 1). The outer spheres depend on the geologically active geosphere for their existence. The magnetosphere is the only sphere that cannot be influenced by humans.

Geodiversity is 'the natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (landforms, topography, physical processes), regolith (including soil) and hydrological features. It includes their assemblages, structures, systems and contributions to landscapes.' (Gray 2013). 'Geodiversity provides the foundation for life on Earth and for the diversity of species, habitats, ecosystems and landscapes.' (Crofts and Gordon 2015).

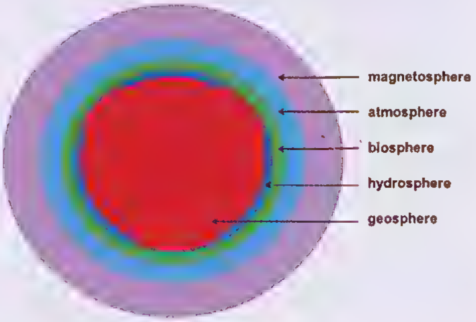

Fig. 1. Earth system.

Geoheritage consists of 'elements of the Earth's geodiversity that are considered to have significant scientific, educational, cultural or aesthetic value' (Crofts and Gordon 2015). The *Australian Heritage Strategy* aims to 'better identify, protect and manage Australia's geoheritage with a grand objective of truly celebrating and caring for all of our natural heritage, both abiotic and biotic' (Commonwealth of Australia 2015; Worboys 2015).

Conservation geology is applied internationally to protect geodiversity and geoheritage, and to support geotourism (O'Halloran *et al.* 1994; Marinos *et al.* 2001; Reynard *et al.* 2009) through geoconservation, which is 'the conservation of geodiversity for its intrinsic, ecological and (geo)heritage values' (Sharples 2002). Geoconservation aims to maintain representative diversity of geological, landform and soil features, and to allow their continued use as research and teaching sites with minimal alteration by humans.

The geodiversity of much of Victoria has been assessed at local and regional scales (e.g. Rosengren 1984, 1988; Rosengren and White 1997; Sharples 2002) and receives a level of statutory protection on public land within the land use category of nature reserve, which is

> an area of land or wetland of particular importance for its significant flora, fauna, natural habitat, geology or geomorphology … includes nature conservation reserve and natural features reserves sub-categories cave, geological and geomorphological features area

(VEAC 2017: 29).

Geodiversity may be overlooked by management plans and during ground operations, even in national parks, due to factors such as fixation on biodiversity, lack of geological awareness, and priority given to infrastructure for managers and visitors over the natural values on which a reserve is based. However, when these areas are viewed as dynamic examples of local and regional natural history, the importance of geodiversity in underlying, complementing and interacting with biodiversity is clear. Biodiversity is draped across the geomorphic surface.

Imported geological material

Imported geological material comes in many forms and includes consolidated concrete and bitumen placed *in situ* and unconsolidated material such as boulders, landfill, hard waste, gravel and sand used in path and track construction. It is usually alien to the site geology. This anthropogenic geomaterial is introduced to make or stabilise infrastructure and is now widespread in many environments including saltmarshes, mangroves and estuaries (Boon *et al.* 2011). Consolidated material can be removed if necessary while unconsolidated material can go feral to become 'lithic weeds'.

Loose surface material from boulders to sand often cannot be contained in the long term. It can readily mobilise and move downslope across adjacent surfaces to become incorporated into soils and landforms, the remaining material forming a lag deposit while it lasts. Washouts of gravel are common. Where placed along waterways and shorelines, loose material can spread offshore and alongshore to adjacent beaches.

Various pressures give rise to proposals to construct breakwaters, dams, roads, bridges, housing and other major infrastructure intrusions into natural areas. These economic-based projects generally involve importing of geomaterial on a large scale and have high impact.

Anthropogenic geomaterial can impact adversely on geodiversity, biodiversity and other environmental values in several ways:

- Covering of geologic, geomorphic and palaeontologic features: natural surface features may be buried under imported geomaterial;
- Covering of biological substrates: biodiversity may be buried and the new surface may be ecologically hostile to native species;
- Imported geomaterial generally detracts from the visitor experience in natural areas. For example boulder walls on coastlines built to protect inland assets from marine inundation form new disfigured landscapes that may not succeed in the long term. Gravel or crushed rock on paths provide a temporary trafficable surface but prevent contact with the soil which can be particularly missed in urban areas with their extensive hard surfaces, and can limit understanding of vegetation patterns where changes in soil type are buried under geomaterial. They are hard or crunchy to walk on, often of a colour unlike local rocks and soil, and can be visually distracting;

- Spread of material into adjacent areas: Most unconsolidated material eventually disperses into adjacent downslope areas, rendering their geomorphic surfaces and soil profiles modified and thereby reducing their natural integrity. Imported gravel may be topped up repeatedly during long-term track maintenance, resulting in repeated permanent increases. Once escaped, imported geological material is useless for its intended purpose, difficult to retrieve and may be a permanent introduction. Dispersing redundant alien geomaterial is effectively anthropogenic lithic litter in the environment;
- Alteration of hydrology: roads, tracks and dams made with imported geomaterial can alter local hydrology by retaining, diverting or concentrating water runoff, sometimes on a large scale. Water quantity may change on particular sites, resulting in effects such as erosion and/or sedimentation of both natural and imported material, and increased growth of introduced plants. Breakwaters have a long history of modifying coastal morphology, sometimes with adverse consequences (Bird 1993);
- Alteration of soil chemistry: change in soil chemistry may be caused by imported geomaterial, such as rise in soil pH in acid soil by leachate from imported alkaline limestone gravel. Most Victorian soils are naturally acidic (VRO 2015) including those of many woodlands and forests on and south of the Great Divide. Adverse effects on acidophilous native vegetation are suspected but not investigated, with a possible example in the Mount Lofty Ranges of South Australia. Increased nutrient content in urban water runoff and then soils stimulates and generally favours weeds;
- Introduction of weeds and pathogens: gravel may contain weeds and pathogens. Weed seeds can be in gravel that has not come directly from a quarry or been stored well. Undisturbed gravel stockpiles eventually grow coloniser weeds and accumulate their seeds, resulting in weed introductions into new areas when the gravel is placed. Gravel also may contain the major introduced pathogen of native vegetation, the water mould *Phytophthora cinnamomi*. The spread of *Phytophthora* from infected sites into parks and reserves is a listed potentially threatening process in Victorian legislation (DSE 2008). An area in Kinglake National Park has been infected by imported gravel, killing grass-trees;
- Contamination of sites of archaeological or cultural value: alien rocks and gravel can interfere with the understanding and appreciation of Aboriginal archaeology and cultural heritage where they are confused with genuine artefacts. The manufacture of gravel by jaw crusher produces impact patterns on gravel identical to those produced by a human striking rocks together (G Vines, pers. comm.). This often challenges researchers and can have consequences: cultural heritage is either not recorded, or places are recorded when they should not be. If a cultural heritage site is pristine, it is better to keep it that way;
- Risk to health and safety: loose geomaterial may spill onto adjacent soils and vegetation and become a slip, trip or eye injury hazard to land managers when maintaining vegetation beside tracks, such as when operating a herbicide spray knapsack or brush cutter. Gravel also may contain silica dust which is a hazardous material made by the manufacturing process (Cancer Council Australia 2017);
- Impacts on geomaterial source areas: geomaterial may be extracted from its source in an unsustainable way, impacting on that site and surrounds. Many quarries are located in environmentally sensitive areas. Granitic sand, for example, may come from an area of remnant native vegetation such as the You Yangs.

Practical issues may warrant the import of geomaterial, such as rock riffles to stop accelerated stream erosion, or gravel for boggy or eroded management vehicle access tracks on conservation area boundaries. However, in managing natural areas, alien geomaterial should be limited to buffer zones, leaving internal core areas and walking tracks in natural condition as far as possible. Locally sourced gravel of the same geology is not alien and can be appropriate, and has been applied in Kinglake National Park, Mornington Peninsula National Park and elsewhere.

Anthropogenic geological material is a geoheritage issue. We contend that this geomaterial can impact on geodiversity, biodiversity and other values and unless it has cultural value it

should not necessarily be accepted as just more Anthropocene deposits. Nature conservation reserves in particular should not be deliberately or accidentally modified in this way. By analogy, if someone were to spray paint on an artistic masterpiece we would regard that as an issue, even though no one would be harmed in the process. Here we have natural masterpieces of nature with land managers in a curatorial role.

Some examples of the use and misuse of imported geomaterial, mostly in natural areas and particularly in nature conservation reserves, are provided in Table 1.

Case studies

The following case studies explore the use of imported geomaterial.

Examples of good practice

Schnapper Point, Mornington

Created from local sandstone, a set of rock steps and pathway leads to and blends with a natural rock outcrop of the same geology at Schnapper Point, Mornington. The local council undertook the state-funded restoration project to solve erosion problems in 1985 (Fig. 2).

There is no quarry for this red sandstone despite its extent in southern Victoria, so rocks in the form of surface and buried floaters that surfaced during roadworks were collected by the council over 20 years. Three stonemasons then cut and installed the slab pavers with sand-cement mortar. Grooves between pavers were kept free of mortar for 25 mm and filled with crushed stone and dust from the cutting process. This ensured that spaces between pavers were red in colour when finished. Indigenous plants have colonised the site, adding to the transition from built to natural. The durable rockwork is as good as on the day it was completed. The result is effective and spectacular.

Moondah Beach, Mount Eliza

Moondah Beach is significant for its diverse geology, geomorphology and palaeontology (Rosengren 1988). The beach has ten types of natural free rock, partly due to the transfer of material around Manyung Rocks from the adjacent Sunnyside North Beach, which has the most geologically complex single kilometre of coastline in Victoria (Neil Archbold, pers. comm., 2002).

Transported by wave action, the many rounded, angular or flat rocks and pebbles include fresh red sandstone, case-hardened brown sandstone, quartz, granodiorite, basalt, carbonate concretions with included fossils, ironstone attracted to magnets, sand solidified into beachrock, and pumice from a submarine volcano in the Pacific Ocean (ABC 2015). Each rock differs in size, shape and colour, and is gradually becoming smaller through abrasion as it travels on a unique trajectory from its source outcrop, which may be on a coastal headland or along a creek such as Gunyong Creek in Gunyong Gorge, which enters the beach. Some have travelled hundreds of metres from recognisable outcrops on Sunnyside. Many are arrested on their journey in stranded beach terraces formed by the mid-Holocene marine maximum in Port Phillip Bay. All were

Fig. 2. Excellent use of local rock forming steps and pathway leading to natural rock outcrop, with designer Douglas Evenden, Schnapper Point, Mornington, February 2016.

Table 1. Use of imported geomaterial (BR = Bushland Reserve; FFR = Fauna and Flora Reserve; NP = National Park; SP = State Park)

Site	Examples of good practice
Importation	
Schnapper Point, Mornington	Local sandstone steps and path
The Esplanade, Mount Martha	Local granodiorite retaining wall beside road
Mornington Peninsula NP, Sorrento	Local crushed limestone on path to beach
Removal	
Half Moon Bay, Black Rock	Foreign sand removed from beach
Black Rock Point, Black Rock	Concrete slabs and rubble removed from beach (Bird *et al.* 1973)
Earimil Bluff, Mount Eliza	Foreign gravel on path replaced with beach sand
Moondah Beach, Mount Eliza	Foreign boulders and cobbles replaced with beach sand
Earimil Creek BR, Mount Eliza	Foreign gravel on path replaced with organic mulch
No importation	
Lava blister, Williamstown	Saved from development after description by Blackburn (1969)
Eastlink Freeway cuttings, Ringwood–Donvale	Spectacular geological cross sections left exposed, not covered by concrete
South East Track, Wilsons Promontory NP	Onsite granite used for walking track construction
Site	**Examples of poor practice**
Warrnambool Coast, Warrnambool	Basalt gravel on walking tracks on limestone coast
Grassland reserve, Caroline Springs	Granitic sand on reserve perimeter instead of natural basalt, advocated in a grassland reserve design manual (Marshall 2013)
Railway cutting, Royal Park	Training ground for generations of geology students has one face covered with foreign material (Blackburn 1969)
Red Bluff, Black Rock	Broken concrete/asphalt slabs and landfill cover coastal cliff
The Pines FFR, Frankston	Gravel on vehicle tracks throughout sandy dunefield terrain
Fossil Beach, Mornington	Foreign rocks, bricks and concrete obscure natural geology
Mornington Peninsula NP, Point Nepean	Granitic gravel on paths on limestone coast, spilling onto orchid site
Mornington Peninsula NP, Greens Bush	Gravel on internal vehicle tracks
Bittern Coastal Wetlands, Hastings	Gravel path placed directly on saltmarsh clay surface instead of making an elevated boardwalk
Wilsons Promontory NP	Basalt boulders at Darby River bridge, basalt gravel on walking tracks to Whisky Bay, Picnic Bay and elsewhere
Mitchell River, below Bairnsdale	Large quantity of rockfill covers riverbank
Ropers Lookout, Alpine NP	Crushed river gravel on viewing platform covers natural volcanic rock
Australian Alps Walking Track, Alpine NP	Large stone blocks and crushed rock paving across stone-free grassland

stranded inland for some 1800 years when the bay was evidently almost dry, starting from around 2800 years BP (Holdgate *et al.* 2011).

The beach has one vehicle landing which was damaged by a storm surge in June 2014. The maintenance department of the local council subsequently placed loose material on the site for beach cleaner access (Fig. 3). As it was within the storm surge zone, the material was soon being mobilised and swept along the beach, affecting the beach's geological integrity and depositing sharp material on the beach, reducing its amenity. The access was temporary while the contamination would have been permanent if not removed—not a solution at all.

Nine months later the council removed the new rock material and replaced it with beach sand (Fig. 4). This is the appropriate material in this sensitive area though it too needs regular replenishment. More underlying alien material forming the landing remains and will eventually need removal if the natural integrity of the beach is to be preserved with sea level rise.

Half Moon Bay, Black Rock

Even beach renourishment has a potential downside if sand of inappropriate texture and colour is used. Half Moon Bay in Black Rock was partially renourished in October 2011 using coarse-grained red sand from a South Gippsland quarry (Fig. 5). The contrast in colour and texture with the existing beach aroused considerable local opposition. A group of influential conservation groups pressured various levels of government to desist and the imported sand was subsequently removed.

Earimil Creek, Mount Eliza

Pale granite gravel was applied to the main walking path in Earimil Creek Bushland Reserve, Mount Eliza, by the local council in the 1990s, whereas the natural geology is red sandstone which produces dark organic topsoil. Although well meant, it was removed and replaced with tree mulch by community volunteers (Fig. 6). Clean tree mulch is reapplied by the council every five years or so, and is sometimes obtained from the site itself, to good effect.

Fig. 3. Foreign material placed on Moondah Beach landing, March 2015.

Fig. 4. Foreign material replaced by beach sand to restore integrity of Moondah Beach, December 2015.

Fig. 5. Foreign sand being laid on Half Moon Bay, October 2011. Photo: *The Age*, 4 October 2011.


Fig. 6. Biodegradable mulch on path, Earimil Creek Bushland Reserve, Mount Eliza, May 2009.

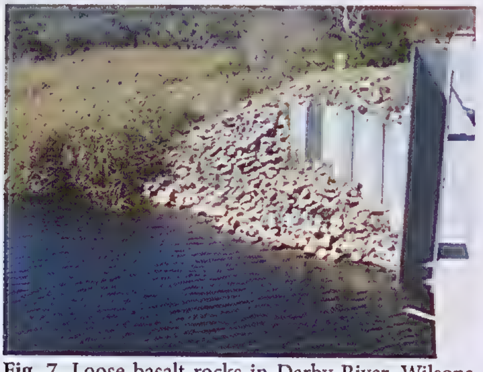
Fig. 7. Loose basalt rocks in Darby River, Wilsons Promontory, December 2015.


Fig. 8. Basalt gravel escaping into the park, December 2015.

Examples of poor practice

Wilsons Promontory

As part of the repair of Darby River bridge in Wilsons Promontory National Park after the 2011 flood, alien basalt rocks were used to stabilise the bridge footings. Basalt rocks are in the river and will spread down to the estuary and onto Darby Beach which has dune limestone geology (Fig. 7).

The Whisky Bay and Picnic Bay areas have been degraded in recent years by basalt gravel laid on white granitic sandy walking tracks leading to the beaches. The basalt soon started leaking into the environment (Fig. 8). It has also been laid on the yellow calcareous sandy track to Cotters Beach.

The Prom once had a dune limestone quarry and a granite quarry for gravel production but in a short-sighted move they were closed as they were considered incompatible with conservation. Unless the same material can be obtained from nearby, a park as large as the Prom could and should have small gravel pits and quarries to produce gravel and stone for internal use. Once retired, recovering extraction sites add habitat diversity in large natural areas, and may support rare species.

Warrnambool Coast

At Warrnambool in western Victoria, basalt gravel has been placed on paths along the dune limestone coast (Fig. 9). The appropriate material was local limestone, which is available. The current management plan specifies local limestone (Yugovic and Arbor 2012).

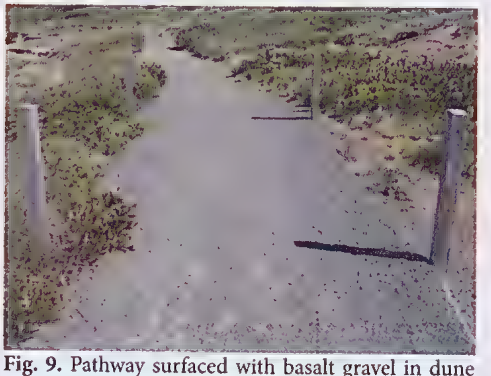
Fig. 9. Pathway surfaced with basalt gravel in dune limestone area, Warrnambool, November 2010.

Fossil Beach, Mornington

A bluestone sea wall and granite boulder wall obscure the geology of part of Fossil Beach, Mornington. Constructed in the 1960s, the sea wall was not necessary as the foreshore reserve is wide in this area. North of the boulder wall is a spread of introduced granite, bluestone, concrete, brick, limestone and other rocks which are mixed with the naturally occurring carbonate concretions and former basalt capping natural lag deposit. The geology is obscured by the muddle of other material giving the area the appearance of a dump site (Vines and Yugovic 2011; Fig. 10).

Fossil Beach is a site of national geologic and palaeontologic significance and is partly protected by an environmental significance overlay in the local planning controls. Although sometimes referred to as Fossil Beach Geological Reserve, there is no statutory framework for such a reserve. The site needs rehabilitation (Rosengren 1988:106).

> Coastal protection and cliff stabilization works have reduced the outcrop area available for sampling and fossil search ... Further coastal protection works or other foreshore or offshore works (including vegetation management, drainage, access) should be designed only in consultation with geological groups with specialist knowledge of the site.

Fig. 10. Boulder wall and mixture of natural rocks and rubble at Fossil Beach, Mornington, October 2017.

Alpine National Park

Stone imported from the lower Kiewa River valley has been used as pavement surface for walking tracks in the Alpine National Park in many places. An example is the use of this light-coloured rounded material at Ropers Lookout where it is in stark contrast geologically and aesthetically with the large, dark, angular basalt blocks that outcrop at this pinnacle (Fig. 11).

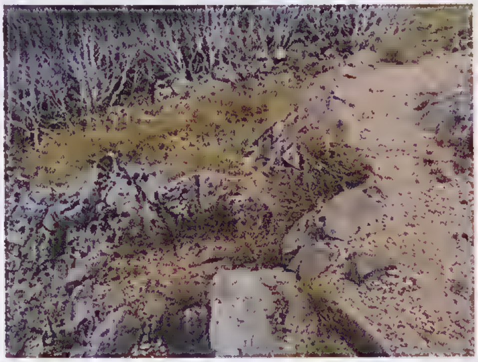

Fig. 11. Crushed lowland river stone used inappropriately at Ropers Lookout, February 2013.

There are many instances along the Australian Alps Walking Track where crushed exotic gravel or large angular blocks have been used as pavement across areas that have no surface stone (Fig. 12).

Fig. 12. Large stone pavers on Australian Alps Walking Track, February 2014.

Washouts of foreign gravel have also occurred in the park (Fig. 13).

Alternatives

The import of foreign anthropogenic geology into natural areas may be avoided through the use of stone and gravel of the same local geology, by appropriate design and construc-

tion using stable synthetic or biodegradable material, or by alternative approaches to management issues and infrastructure development proposals. Planned coastal retreat strategies may be appropriate. Importation becomes the last resort rather than the first resort.

Walking track erosion may be controlled by installing local stone or timber steps, or by breaching and barring — construction of shallow channels and levees diagonally across tracks to divert runoff. Boardwalks can be appropriate. Soil from a nearby site may be imported to fill ruts and cover exposed surfaces for revegetation, and tracks can be closed and relocated to be managed properly.

A range of sensitive erosion control measures can be seen on walking tracks in Victoria such as in Great Otway National Park (Point Addis boardwalk), Werribee Gorge State Park and Wilsons Promontory National Park. Synthetic material as a pavement is preferred to inappropriate geological materials (Fig. 14). At least future researchers will be able to identify the material as synthetic rather than go through geological hoops to try to explain the occurrence of exotic geology.

In Tasmania, local rock is recommended for walking tracks in national parks (DPIPWE 2011: 38, 45):

> Field staff in some areas have in recent years favoured the use of local rock for hardening tracks, in some cases flying rock to work sites from several kilometres away. When undertaken by experienced trackworkers, the use of rock can be cost-competitive with other hardening techniques such as duckboard and even double planking. Like all track infrastructure rock steps and paving require regular maintenance, but they are resistant to fire damage and could potentially last for centuries. (Note that gravel tracks can suffer a degree of fire damage if timber edging is burnt or if underlying root structures are damaged, and even rock can be damaged by extremely hot fires.
>
> It is recommended that tracks be stabilised and upgraded using local rock, stone and gravel as far as possible, as these materials blend in well with the natural environment, are relatively low-maintenance and are largely immune to fire damage.

Skilled Tasmanian track workers were brought in to construct the South East Track in Wilson Promontory National Park, using hand winches and onsite granite (*The Age* 1998).

Access and erosion may be addressed through application of organic mulch. Mulch contains nutrients which could increase weed growth adjacent to paths but if the mulch is sourced from the site itself this may not be significant. Clean mulch is a benign biodegradable biomaterial. It generally integrates better into the substrate than gravel, remains for longer, and is less expensive. Not being permanent, it may need periodic reapplication, as does gravel, but is cheaper. The ideal mulch is made from tree prunings from the site itself, especially in areas of low soil fertility. Organic mulch is soon compacted by walkers, making it suitable for wheelchairs and baby strollers.

The lining of rivers and creeks with concrete or rock beaching extending from top to bottom of the bank degrades the natural values of streams but is used much less than in former times. Now incised and/or laterally unstable

Fig. 13. Gravel washout, Cope Creek track, Bogong High Plains, December 2017. Photo: Zac Walker.

Fig. 14. Synthetic material used on path, Australian Alps Walking Track, February 2014.

streams mainly receive graded rockfill placed as bed control riffles (to restore bed stability) and as lower bank toe protection (to resist bank erosion), which means less imported geomaterial. Constructed riffles, which maintain fish passage and limit flow turbulence, are now preferred to vertical drop structures (large stacked rocks or concrete/timber/steel structures) on stream beds. Rock used in riffles and bank protection works 'must match the local area's natural geology' and existing geomorphic features 'should be maintained' (Melbourne Water 2009). There is less concern for geological compatibility of rockwork on banks in urban and industrial areas.

Many significant exposures of geological materials occur on river and coastal cliffs as a result of ambient recession or erosion of slopes, e.g. Eagle Point Bluff on the lower Mitchell River. These are often in places where the recession threatens natural and built 'assets' and may create a hazard for users, but it is this very process that creates or maintains the significant feature. A case-by-case assessment of the perceived and actual hazard is necessary before a sometimes counterproductive hard-engineering response is applied.

Consolidated foreign geomaterial such as concrete or bitumen is easier to manage than unconsolidated material as it is more stable and more easily retrieved. However, if left alone it too will eventually break down and be mobilised. While they last, installed structures also blend in with the environment better when stained with pigment similar to the local rock colour.

Management guidelines

The following guidelines are proposed to promote the appropriate use of imported geomaterial in the protection and management of natural areas.

1. Develop and maintain an inventory of geoscience values and their sensitivity in nature conservation reserves.
2. Include geodiversity values in management plans.
3. Avoid the importation of alien geomaterial where possible.
4. Consider non-intrusive means of addressing access and erosion issues.
5. Evaluate proposals to import geomaterial, considering (a) proposed use, (b) alternatives, and (c) costs and benefits for geodiversity and biodiversity with regard to source and recipient sites.
6. Consider use of materials such as gravel sourced from local geology, or organic mulch.
7. Consult with experts for advice on the type and source of suitable matching geomaterials.
8. Ensure that public artwork, monuments, pathways and other infrastructure involving imported geomaterial match the site geology or are geologically compatible with the site.
9. Remove inappropriate imported geomaterial where practicable.
10. Take measures to protect and interpret the geoheritage of natural areas.

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Some observations of Australasian Grebes *Tachybaptus novaehollandiae* on and near a flood-retarding basin in Clayton, Victoria, together with comments on the habitat

Introduction

The Australasian Grebe *Tachybaptus novaehollandiae* is the smallest grebe found in Australasia. It is widely distributed in Australia, and inhabits a variety of fairly shallow bodies of fresh water, generally with some fringing vegetation. It is secretive and wary, and usually occurs singly or in monogamous pairs. Water-courtship can occur at any time, and nesting takes place up to three times per year. The nest consists of a soggy platform of water weeds, and is concealed amongst vegetation. Both sexes incubate the eggs for a period of about 23 days. The young birds are fed by the parents until they are old enough to find their own food, and are fully independent at eight weeks of age. Juveniles from one brood sometimes feed smaller siblings from the next brood. Breeding losses are thought to be high because of fluctuating water levels, weather and predation. Grebes attack intruders by skidding across the water towards them, or by diving and biting from under the water (Marchant and Higgins 1990).

Australasian Grebes have been breeding at the flood-retarding basin located at Monash University's Clayton campus, in suburban Melbourne, Victoria, every year since 2006, and three times per year since 2009. The basin (Fig. 1) is approximately 180 m north-west of another freshwater body in Jock Marshall Reserve, also inhabited by Australasian Grebes. At the basin, bulrushes *Typha* sp. grow at the eastern and western ends and along part of the northern side. The water weed *Vallisneria gigantea* (Fig. 2) is well established, except in deeper water. Only one pair of Grebes at a time occupies the territory.

From October 2006 to March 2018, through opportunistic observations made during walks around the basin, as well as more frequent observations during 2017 and 2018, it has been

possible to gain some insights into the lives of these tantalisingly secretive birds.

Observations

Mating

Surprisingly, no courtship behaviour has been seen, and mating was witnessed on only one occasion. On 24 October 2017, two adult Grebes were swimming near the northern side of the basin, with their month-old youngster following closely. Suddenly, both adults swam quickly to their nest platform amongst the bulrushes and mated there. The youngster remained at a respectful distance during this brief episode.

Interval between mating and nesting

By 4 November 2017, 11 days after they were seen mating, the Grebes had built a new nest amongst the bulrushes at the western end of the basin, and there was one egg in it on 6 November.

Nesting

A pair of Grebes takes up to a week to construct a nest. They can be seen carrying nest material to the chosen site, usually amongst the bulrushes but occasionally amongst the water weed. Once incubation begins after the first one or two eggs have been laid (Marchant Higgins 1990), the birds dive and approach the nest from under water so as not to reveal its whereabouts. Eggs are laid at intervals, 'probably of up to 48 hours or irregular' (Marchant and Higgins 1990: 97). During the day, each bird sits on the nest for about 45 to 75 minutes while its partner feeds. The image on the front cover shows a change-over taking place, with one bird leaving as the other arrives.

Sometimes one bird calls to the other before the change-over, sometimes they call when they change positions, and at other times they carry out the procedure in silence. Occasionally, the incubating bird covers the eggs with water weeds before leaving, either voluntarily or because of disturbance.

Brood and clutch size

Brood size has varied from one to five, and there have been several cases where only one or two young birds were produced. The number of eggs laid is known from only two direct observations—on 16 September 2016, when there were four eggs (see front cover), and on 30 August 2017, when there were two eggs—and by deduction, on observing a brood of five young. Marchant and Higgins (1990: 97) cast doubt on this species' ability to lay more than five eggs per clutch.

Fig. 1. Flood-retarding basin at Monash University Clayton campus. View from western end.

Fig. 2. Water weed *Vallisneria gigantea* at the basin.

Brooding the young

The young are brooded on the nest solely for one night after hatching (Marchant *et al.* 1989; Marchant and Higgins 1990), but this behaviour has not yet been observed at the basin. In 2009, when the Grebes nested in water weed, at least one of the young had hatched on 24 January, but another observation was not made until 27 January, when the adults were swimming with three young. When the Grebes nest in bulrushes, their young seem to be kept hidden amongst the bulrushes until after the last

one has hatched, by which time the first can be close to one week old and noticeably larger than its siblings.

Feeding the young

Grebes eat fish, snails and aquatic arthropods (Marchant and Higgins 1990). An adult bringing food to its nest signifies that at least one young bird has hatched. Adults usually feed their young bill to bill, but if a prey item is large enough to be broken up, the young retrieve the pieces from the water. On 30 October 2017, it was interesting to see an adult swim purposefully across the basin, carrying a small fish that it dropped into the water in front of its youngster, which then had to dive to retrieve its meal.

Although juveniles from one brood are reported to feed young birds from the next brood (Marchant and Higgins 1990; Fjeldså 2004), this behaviour has not been observed at the basin. However, there was an instance in March 2009 when an intruding adult in breeding plumage kept company with, and fed, one young bird from a brood of three, while the parent birds each looked after one of the other two siblings (Hubregtse 2010). At the time, J Fjeldså (pers. comm.) said that grebes are known to return to their natal water body, and suggested that the intruder may have been accepted because it had some sort of social bond with the breeding pair.

Presentation of weed to parent

On 25 February 2018, it was interesting to see an eight-week-old Grebe try to present a piece of weed to its parent. The parent ignored it. Marchant and Higgins (1990: 96) state that presentation of weeds is part of courtship behaviour, but they also mention that 'Juveniles show [a] large repertoire of adult behaviour'.

The young Grebes that 'stayed home'

Two young Grebes stayed at the basin much longer than any others have done, one in 2017 and the other in 2018.

During March 2017, a pair of Grebes nested amongst the bulrushes on the northern side of the basin. On 11 April the Grebes were seen with two young, the larger of which appeared to be at least two weeks old.

The young birds developed normally, and the elder of the two was no longer seen once it reached about eight weeks of age. The younger bird stayed with one of its parents. It continued to call for food, and when its request was refused it would sit on the water, waiting for the parent to surface, and quickly grab food from its bill. Although able to feed by itself, it was still calling for food on 26 July, but had stopped by 30 July, when it was approximately 16 weeks old—twice the age at which it should have gained full independence. From this time on it fed alone, usually well away from its parents.

It is normal for young Grebes to pester their parents for food long after they are capable of finding it for themselves, and also to snatch food from a parent's bill but, at the basin, this was the first time a young Grebe had behaved this way for so long. Moreover, this was the first time a young Grebe had stayed at the basin beyond the age of about eight weeks—six months in this instance.

The surviving Grebe from the brood that hatched at the end of December 2017 fed independently from about 12 weeks of age, but was still keeping company with its remaining parent on 7 August 2018. The two birds were often seen close together and, when apart, called before approaching one another.

Time taken to acquire breeding plumage

The young Grebe that stayed at the basin for six months acquired breeding plumage shortly before it (presumably) departed. The second youngster that stayed acquired breeding plumage at approximately 18 weeks of age. Mo and Waterhouse (2015a: 298) found one young Grebe that 'assumed adult plumage' at about 12 weeks of age. M Mo (pers. comm., 22 December 2017) confirmed that this bird was in breeding plumage. So it seems that the age at which breeding plumage is acquired can vary considerably.

Single parent

On 12 February 2011, a pair of Grebes were building a nest, and one bird was on the nest from 16 February. On 6 March and subsequently, one of the adults was absent. By 11 March two young had hatched, and the remaining adult reared them successfully on its own. On 15 April a second adult Grebe was present, but it stayed well away from the adult with the young ones, and was still keeping away from them on 22 April and 5 May.

Movement of nests and eggs during flooding
Since 2006, flooding has destroyed five nests and their contents, but several nests survived inundation. Two of these, and most likely three, with eggs, were moved from their original locations, probably by the movement of the water. It is not known if the Grebes are capable of assisting in this process. In an attempt to find out, one visit was made to the basin during very heavy rain, but to no avail because the nest in question had already been wrecked.

2008
The first relocation occurred when a nest constructed amongst the water weeds in the north-western section of the basin disappeared after heavy rain on the night of 6 February. The Grebes were not seen for more than two weeks, but on 23 February they were calling from near the bulrushes at the western end of the basin. The following day they were seen at the same place with four young (Hubregtse 2010).

2010
When flooding occurred on 12 December, a nest moved several metres (Fig. 3). This nest also produced four young, which were seen on 17 December. One of the young disappeared during another flood on 20 December—the first to be lost since the Grebes started breeding at the basin.

2017
On 17 November, flooding moved a nest at the western end of the basin by a couple of metres. On 26 November, after more flooding, an adult Grebe was seen sitting on a nest in the bulrushes on the northern side of the basin, roughly 50 m from the site at the western end. On 1 December, an adult brought something that seemed to be a food item to the nest. Since the first egg was seen in the nest at the western end of the basin on 6 November, young would have started hatching about 29 November. The prospect of demonstrating that eggs could be moved such a long distance was very exciting but, to be absolutely certain, it would be necessary to see at least one young bird. Unfortunately, an even bigger flood on 2 and 3 December completely destroyed the nest and its contents.

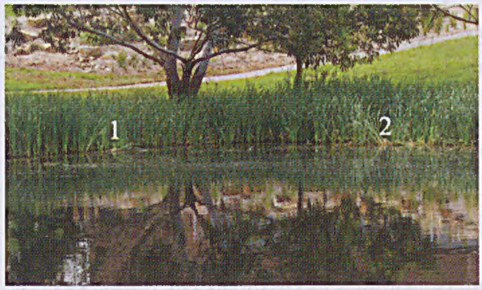

Fig. 3. During a flood in December 2010, the nest that had been at location 1 was moved to location 2.

Behaviour after a nest is destroyed
Adult birds have been seen on a few occasions after a nest and eggs have been destroyed. They swim some distance apart and call frequently. Within a few days, they start to build another nest. For example, after the destruction of their nest on 2–3 December 2017, they were seen constructing a new nest at the western end of the basin on 8 December. By 10 December, another flood had washed away that nest, but on 15 December the Grebes were carrying nesting material to a site on northern side of the basin, near where their March 2017 nest had been.

Breeding outcomes
From October 2006 to December 2017, Australasian Grebes have nested or attempted to nest at the basin on 33 occasions. Six of these nests (18%) failed, one because of inadvertent human disturbance (Hubregtse 2010), and five because of flooding. The remaining 27 nests produced 74 young (though some young birds could have disappeared before there was a chance to observe them). Six young (~8%) are known to have disappeared before they were old enough to leave, and the remaining 68 reached maturity. Sixty-six of these were no longer seen after reaching full independence at about eight weeks of age, presumably because they departed. Of the two others, one stayed for six months, and the other was still present on 7 August 2018, more than seven months after hatching (see The young Grebes that 'stayed home', above).

Losses
Losses were greatest in January 2018. At the basin, one adult and three young disappeared, while at nearby Jock Marshall Reserve, one

adult and four of five young disappeared. No dead birds have been found, and predation has not yet been observed.

Possible predators

Red Foxes *Vulpes vulpes* have lived in the area for many years, but it is not known if they interfere in any way with the Grebes. A number of bird species live at or visit the basin (Table 1). A few of these could be responsible for the disappearance of Grebe eggs or young. According to 'Life in the Suburbs' website, Silver gulls *Chroicocephalus novaehollandiae* and Australian Ravens *Corvus coronoides* may steal eggs or attack the young. The Australian Raven does not live at the basin, but the Little Raven *C. mellori* does, and one has been seen standing on a eucalypt branch overlooking a Grebe nest that had an egg in it. The Raven was unperturbed by human presence, and remained on the branch when approached.

It is interesting to note that, at Moore Reserve wetland in Sydney, Mo and Waterhouse (2015b) saw a Dusky Moorhen *Gallinula tenebrosa* capture a young Australasian Grebe in its bill and drag it under the water; this victim survived the attack after parental intervention. These authors also suspect that the Eurasian Coot *Fulica atra* might kill young Grebes. Dusky Moorhens are resident at the basin but no interaction with the Grebes has yet been observed. Interactions with Eurasian Coots are mentioned below.

Interactions with other birds

Most interactions with other birds (six species in all) were noted only during the breeding season.

Australasian Grebe

In March 2009, two intruding Australasian Grebes in breeding plumage came to the basin and were attacked vigorously by the resident pair of Grebes, which had three young at the

Table 1. Birds at the basin in Monash University Clayton campus. Species that have not been seen for more than three years have been omitted.

Species	Frequency
Australian Wood Duck *Chenonetta jubata*	Common
Grey Teal *Anas gracilis*	Intermittent
Chestnut Teal *Anas castanea*	Intermittent
Pacific Black Duck *Anas superciliosa*	Common
Hardhead *Aythya australis*	Rare
Domestic Goose *Anser* sp.	One resident
Australasian Grebe *Tachybaptus novaehollandiae*	Resident
Tawny Frogmouth *Podargus strigoides*	One pair resident
Australasian Darter *Anhinga novaehollandiae*	Rare
Little Pied Cormorant *Microcarbo melanoleucos*	One or two often present
Little Black Cormorant *Phalacrocorax sulcirostris*	Intermittent
White-faced Heron *Egretta novaehollandiae*	Intermittent
Australian White Ibis *Threskiornis molucca*	Intermittent
Straw-necked Ibis *Threskiornis spinicollis*	Intermittent
Buff-banded Rail *Gallirallus philippensis*	Rarely seen but possibly resident
Dusky Moorhen *Gallinula tenebrosa*	Common
Eurasian Coot *Fulica atra*	Common
Masked Lapwing *Vanellus miles*	One pair usually present
Silver Gull *Chroicocephalus novaehollandiae*	One usually present
Galah *Elophus roseicapillus*	Intermittent
Long-billed Corella *Cacatua tenuirostris*	Intermittent
Little Corella *Cacatua sanguinea*	Intermittent
Rainbow Lorikeet *Trichoglossus haematodus*	Intermittent
Musk Lorikeet *Glossopsitta concinna*	Intermittent
Spotted Pardalote *Pardalotus punctatus*	Intermittent
Noisy Miner *Manorina melanocephala*	Very common
Grey Butcherbird *Cracticus torquatus*	Intermittent
Australian Magpie *Cracticus tibicen*	One pair usually present in grassed areas
Pied Currawong *Strepera graculina*	Intermittent
Little Raven *Corvus mellori*	Common
Magpie-lark *Grallina cyanoleuca*	One pair resident
Welcome Swallow *Hirundo neoxena*	Present for most of the year

time. Ultimately, one of the intruders was tolerated (see 'Feeding the young', above).

Silver Gull
A lone Silver Gull is usually present at the basin. On 12 April 2017, the Gull attempted to snatch food from a surfacing adult Grebe, but didn't succeed.

Australian Wood Duck Chenonetta jubata
On 15 October 2017, the female of a pair of Australian Wood Ducks chased a young Grebe, which immediately dived. The Wood Duck attacked a few more times, but her partner had ignored the situation and moved on, so the female swam away to join him. The parent Grebes took no notice of this incident, possibly because at that time the Wood Ducks were just visitors, not residents.

Eurasian Coot
Eurasian Coots are residents at the basin. Grebes with young chase the Coots, and Coots with young chase the Grebes. On 16 October 2017, when one Coot chased a young Grebe a couple of times, the parent Grebes approached the offender, dived simultaneously and attacked it from underneath (no doubt by biting it), giving it such a surprise that it leapt above the surface of the water and subsequently went ashore.

Little Black Cormorant Phalacrocorax sulcirostris
On 12 November 2017, a Little Black Cormorant briefly harassed an adult Grebe sitting on a nest, but the Grebe defended itself and the Cormorant quickly swam away.

Noisy Miner Manorina melanocephala
A few years ago, a group of Noisy Miners was seen mobbing an adult Grebe that was on grassy ground inside and next to the netting fence in the north-western corner of Jock Marshall Reserve, some 40 m east of the basin. Without human disturbance, it is probable that the Miners would have killed the Grebe, which was motionless and apparently paralysed by fear. Previously, Miners had killed a Spotted Dove *Streptopelia chinensis* and a Crested Pigeon *Ocyphaps lophotes* near the western end of the basin. According to Marchant and Higgins (1990: 93), Australasian Grebes are 'only accidentally on land', and probably undertake long-distance flights at night. However, the basin is only a short distance from Jock Marshall Reserve, so the victim may have been brought down by the Miners while flying towards the basin from the water body in the Reserve. An hour after being found, the Grebe had gone.

Comments on the condition of the basin
Rubbish
It is regrettable that some people regard the basin as a convenient place to leave rubbish, usually around the perimeter, where wind can transport it into the water. Drink cans, bottles, discarded clothing, paper cups and plastic bags are just some of the items that litter the area (see Fig. 4). Each time flooding occurs, much of this clutter is cleared away after it collects on the outlet grille, but there is always plenty left behind and more to come. This cannot be good for the habitat.

Algae
'Life in the Suburbs' website states that 'water bodies in urban areas are less resilient against periods of drought or extreme weather events, [which cause] a build-up of toxins and dangerous algae levels that may impact on the health of [Australasian Grebes]'. At the basin, algae grow in profusion, especially during warm dry weather when the water level is low.

Decrease in biodiversity
As far as can be ascertained, there are no longer any frogs at the basin, and there are fewer dragonflies and damselflies than in the past.

Fig. 4. Rubbish in the water at the eastern end of the basin, with a White-faced Heron (top right).

An invasive, introduced mosquitofish *Gambusia* sp. is present in huge numbers, and would no doubt be a negative influence on these creatures (e.g. Turner 2017; Wikipedia website). Mosquitofish consume the eggs of the Wandering Percher dragonfly *Diplacodes bipunctata* as soon as they are laid in water (Hubregtse 2011), but a few of these dragonflies are still present. Mosquitofish are preyed on by various water birds, such as White-faced Heron, Little Black and Little Pied Cormorants and Australasian Grebes, but this does not seem to affect their numbers.

Some bird species that used to visit the basin have not been seen there by the author for several years. These include Black Swan *Cygnus atratus*, Australian Pelican *Pelicanus conspicillatus*, White-necked Heron *Ardea pacifica* and Eastern Great Egret *Ardea modesta*. There has been a decrease in numbers of some species, such as White-faced Heron, which has been known to breed at the basin—now only a solitary bird is seen occasionally. Such declines are no doubt exacerbated by the general loss of habitat caused by continuous urban sprawl.

Conclusion

Australasian Grebes are particularly interesting birds, the more so because of their secretive nature. Observing them raises a number of questions. Where do they go when they leave the basin? What happened to those that failed to reach maturity? If they are preyed on, what are the predators? The unexplained disappearance of so many Grebes in January 2018 is alarming. Close monitoring of future breeding events may be necessary to find out what is happening.

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